# INJURY TO GROWING CROPS CAUSED BY THE APPLICATION OF ARSENICAL COMPOUNDS TO THE SOIL[1]

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## INTRODUCTION

In a preliminary paper (*14*) [2] brief mention was made of the report of Headden (*8*) on the injury to crowns of fruit trees in Colorado caused by the use of arsenicals, and a detailed outline was given of a series of experiments made by the writers for the purpose of determining whether the arsenical compounds commonly used as insecticides are injurious to the bark of fruit trees, the nature and extent of injury, the relative toxicity of different arsenicals, and the conditions most favorable to injurious action.

The work here recorded, which was done between 1911 and 1922, at Bozeman, Mont., and at Madison, Wis., presents another phase of the general problem of the effect of arsenical compounds on plant life, but deals primarily with the results obtained by adding the chemical to the soil.

## HISTORICAL REVIEW

A review of early literature reveals the fact that arsenical compounds, especially arsenic trioxide, were known in ancient times. Arsenic was early recognized as a typical poison for plants as well as animals, and its effects upon plant life have been the subject of investigation for many years.

De Candolle (*3, p. 1328–1332*) in 1832 refers to the work of Jaeger, Marcet, and Macaire and reviews in considerable detail the work of Leuchs, who found a decrease in dry weight of vetch plants when grown in the presence of arsenic trioxide.

Chatin (*4*) discovered that arsenic absorbed by the roots was distributed to various tissues of plants.

Davy (*1*) concluded from his work on the effect of arsenic on growing plants: (1) That plants, at least peas and turnips, are not injured by arsenic in the soil; (2) that they absorb this dangerous element; and (3) that they retain it in their tissues.

Daubeny (*5*) watered barley plants five times in succession with a solution of arsenious acid, 1 ounce in 10 gallons of water, and found that the crop matured a fortnight earlier, but that the amount of grain harvested was less than the normal yield. Four waterings of turnips with the same solution did not hasten maturity, but slightly decreased the yields. Analysis did not indicate any arsenic in the tissues.

Gorup (*7*) grew to maturity plants of *Polygonum fagopyrum*, *Pisum sativum*, and *Secale sativum* in soil containing arsenious acid, 30 gm. of the acid in 30.7 cu. decim. of soil, each unit growing two plants which matured normally. Analysis by Marsh's test showed

[1] Received for publication June 1, 1926; issued January, 1927.
[2] Reference is made by number (italic) to "Literature cited," p. 77.

no trace of arsenic in 20 gm. of dry matter of *Secale cereale*, but in 148 gm. of *Polygonum fagopyrum* a weak mirror was formed. He concluded that these plants, especially *Pisum sativum*, are indifferent to relatively large quantities of arsenious acid in the soil.

Freytag (*6*) found that one-eightieth per cent of arsenious acid in water culture solution was fatal to beans, peas, and other plants, and he concluded that plants have not a selective power since they absorb poisonous as well as nutritive substances.

McMurtie (*10*) concluded from his work that plants have not the power to absorb and assimilate compounds of arsenic from the soil but that such compounds may exert an injurious influence upon vegetation, although not until the quantity present reaches in the case of Paris green about 900 pounds per acre, in the case of arsenite of potash about 400 pounds per acre, and in the case of arsenate of potash about 150 pounds per acre.

Phillips (*12*), experimenting with greenhouse plants, found that calcium arsenate when present in the soil in toxic amounts checked the formation of roots to such an extent as to interfere with nutrition and growth, or else it killed the plant outright. Analyses showed no traces of arsenic in the poisoned plants.

Nobbe, Baessler, and Will (*11*) found that one part of arsenic in one million parts of water had an injurious effect on buckwheat, oats, maize, and peas when grown in water culture.

Blyth (*2*) stated that if plants are poisoned with arsenic, the toxic action may be traced from below upwards, and analyses will detect minute quantities of arsenic in all parts of the plant.

Lyttkens (*9*) found that the addition of 0.005 to 0.01 per cent of arsenious acid (as the potassium salt) to garden soil in which barley was growing caused a feeble growth and a blue-green color.

In regard to the occurrence of arsenic in plant tissues, a great deal of work has been done, and the general conclusion has been reached that arsenic is quite generally a constituent of plant tissue when plants are grown in its presence.

Wanklyn (*16*), discussing arsenic, says that "minute traces of arsenic are all-pervading, and, as necessary consequence, the mere detection of arsenic is devoid of meaning unless it is, to some extent, a quantitative operation."

## DESCRIPTION AND RESULTS OF EXPERIMENTS

### TRANSPIRATION STUDIES WITH OAT PLANTS IN WATER CULTURES

A group of preliminary experiments was made with oat plants in water cultures.

The containers used were ordinary wide-mouthed flint glass bottles of approximately 530 c. c. capacity, covered with a uniform coat of varnish. They were cleaned with a sulphuric-potassium-chromate cleaning fluid and thoroughly rinsed with distilled water. The water was obtained by double distillation; its conductivity, tested at different times, varied from 4 to 6 times $10^{-5}$ ohms. The chemicals of a high degree of purity, were as follows: Arsenic trioxide, by analysis 73.1 per cent arsenic; calcium nitrate; ferric chloride; magnesium sulphate; potassium phosphate (monobasic); Shive's (*13*) 3-salt nutrient solution No. R5C2, which contained potassium phosphate, 0.018 m., calcium nitrate, 0.0052 m., magnesium sulphate, 0.0150 m; and ferric chloride 0.068 per cent solution, 5 c. c. to each 500 c. c. of nutrient solution.

Oat plants (Foundation Wisconsin Wonder Stock Pedigree No. 1) were used in all experiments. These were germinated in moistened pure quartz sand, and the seedlings were supported over the nutrient solution by the method described by Tottingham (*15*). When arsenic trioxide was used in the solution, it was added at the rate of a definite number of parts per million calculated as metallic arsenic.

The loss of weight by transpiration was determined at the end of each week by weighing the cultures, and enough distilled water was added at each weighing to compensate for the loss by transpiration. In some of the experiments the plants were severed just above the remains of the seeds, and the tops were dried at a constant temperature of 102° C. until they became constant in weight. The results of these experiments are recorded in Tables 1, 2, and 3.

TABLE 1.—*Loss of water by oat plants grown in Shive's nutrient solution with and without the addition of arsenic trioxide*

| Culture No. | Arsenic, parts per million | Water lost (grams) | | | | Appearance of plants |
|---|---|---|---|---|---|---|
| | | First week | Second week | Third week | Total | |
| 1 | 0 | 9.5 | 23.5 | 35.5 | 68.5 | Normal color, leaf blade broad. |
| 2 | 0 | 10.0 | 23.0 | 36.5 | 69.5 | |
| 3 | 1 | 10.0 | 19.0 | 20.5 | 49.5 | Light-green color, leaf blades narrower than Nos. 1 and 2. |
| 4 | 1 | 9.0 | 17.5 | 19.0 | 45.5 | |
| 5 | 3 | 6.5 | 12.0 | 14.0 | 32.5 | Lighter colored, and leaf blades narrower than Nos. 3 and 4. |
| 6 | 3 | 6.0 | [a] 9.5 | 10.5 | [b] 26 | |

[a] One plant made no growth, probably because of fungous attack.
[b] No allowance is made for dwarfed plant.

TABLE 2.—*Loss of water by oat plants grown in Shive's nutrient solution, with and without the addition of arsenic trioxide*

| Culture No. | Arsenic, parts per million | Water lost (grams) | | | | | Dry weight of tops in grams | Appearance of plants |
|---|---|---|---|---|---|---|---|---|
| | | First week | Second week | Third week | Fourth week | Total | | |
| 1 | 0 | 3.5 | 10.0 | 22.5 | 48.5 | 84.5 | 0.1990 | Leaf blades broad, normal color, average height 400 mm. Average length roots 85 mm. |
| 2 | 0 | 1.5 | 8.5 | 23.5 | 44.5 | 78.0 | .1820 | |
| 3 | 0 | 3.0 | 10.0 | 24.5 | 50.0 | 87.5 | .1974 | |
| 4 | 5 | 2.0 | [a] 6.0 | 6.0 | 9.5 | [b] 23.5 | [b] .0630 | Leaf blades slightly rolled, light-green color, average height 200 mm. Average length roots 25 mm. |
| 5 | 5 | 2.5 | 4.5 | 4.5 | 12.0 | 23.5 | .0622 | |
| 6 | 5 | 1.0 | 4.0 | 7.0 | 11.5 | 23.5 | .0854 | |
| 7 | 10. | 1.5 | 3.5 | 5.0 | 13.0 | 23.0 | .0778 | Color light green. Average height 165 mm. Average length roots 25 mm. |
| 8 | 10 | 1.5 | [a] 3.0 | 4.5 | 9.0 | [b] 18.0 | [b] .0591 | |
| 9 | 10 | 1.0 | 2.5 | 4.5 | 11.5 | 19.5 | .0614 | |

[a] One plant dead.
[b] No allowance is made for dead plant.

TABLE 3.—*Loss of water by oat plants grown in Shive's nutrient solution, with and without the addition of arsenic trioxide*

| Culture No. | Arsenic, parts per million | Water lost (grams) | | | | Dry weight tops (grams) | Appearance of plants |
|---|---|---|---|---|---|---|---|
| | | First week | Second week | Third week | Total | | |
| 1 | 0 | 12.0 | 31.0 | 56.0 | 99.0 | 0.3270 | Good color, root system well developed; leaf blades broad. |
| 2 | 0 | 8.5 | 30.5 | 58.5 | 97.5 | .3160 | |
| 3 | 0 | 10.0 | 29.5 | 55.0 | 94.5 | .3300 | |
| 4 | 5 | 7.0 | 17.0 | 13.5 | 37.5 | .1212 | Light-green color; root system poorly developed; leaf blades narrow. |
| 5 | 5 | 6.5 | 13.5 | 12.0 | 32.0 | .1090 | |
| 6 | 5 | 9.5 | 15.5 | 17.0 | 42.0 | .0936 | |
| 7 | 10 | 5.0 | 8.0 | 8.5 | 21.5 | .0682 | Similar to 4, 5, and 6, but all effects more noticeable. |
| 8 | 10 | 4.5 | 5.0 | 2.5 | 12.0 | .0628 | |
| 9 | 10 | 8.5 | 9.0 | 9.5 | 27.0 | .0694 | |

Tables 1, 2, and 3 show rather conclusively that arsenic added as arsenic trioxide decreases transpiration, even when added at the rate of one part per million. The treated plants were characterized by a lighter-green foliage and narrower leaf blades than the control. While all plants were treated similarly, the results indicate considerable individuality in the plants themselves.

## TRANSPIRATION STUDIES WITH TOMATO PLANTS POTTED IN SOIL

Tomato plants were given the ordinary cultural care of a well-managed greenhouse until the plants were about 8 inches tall and of a size suitable for transpiration work. Throughout the experiments all plants were kept as nearly as possible under similar conditions of light, temperature, and humidity.

In determining the amount of water lost by transpiration the soil and pot were so sealed as to allow no loss of water except through the aerial parts. A quantity of water equal to that lost by the plants was added daily, all losses being determined by weighing on scales sensitive to 0.5 gm.

In beginning an experiment, transpiration records were taken for a period of days, usually six, and the plants were then divided into groups of three each. One of these groups was retained as a control, and to the others a single application of arsenic trioxide in solution was added in different proportions after weighing the plants on the sixth day, and the experiments continued. The arsenic trioxide was added as a definite number of parts per million of metallic arsenic based upon the amount of moisture in the soil. The results of these experiments and of similar experiments with sodium arsenite and potassium arsenite are shown in Tables 4 to 7 and in Figures 1 to 4.

TABLE 4.—*Daily loss of water by Everbearing tomato plants growing in soil, with and without the addition of arsenic trioxide, the chemical added after the plants were weighed on the sixth day*

SERIES 1

| Day | Loss of water in grams by control | | | | Loss of water in grams after addition of— Arsenic 25 parts per million | | | | Arsenic 37.5 parts per million | | | | Arsenic 50 parts per million | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | a | b | c | Total | a | b | c | Total | a | b | c | Total | a | b | c | Total |
| 1 | 41 | 39 | 29 | 109 | 34 | 29 | 44 | 107 | 33 | 31 | 44 | 108 | 35 | 26 | 51 | 112 |
| 2 | 31 | 29 | 23 | 83 | 24 | 20 | 31 | 75 | 23 | 25 | 29 | 77 | 24 | 20 | 32 | 76 |
| 3 | 60 | 63 | 48 | 171 | 44 | 41 | 79 | 164 | 51 | 46 | 63 | 160 | 48 | 40 | 63 | 151 |
| 4 | 48 | 45 | 33 | 126 | 41 | 34 | 54 | 129 | 37 | 38 | 48 | 123 | 47 | 36 | 49 | 132 |
| 5 | 72 | 66 | 49 | 187 | 51 | 46 | 83 | 180 | 63 | 53 | 71 | 187 | 59 | 49 | 71 | 179 |
| 6 | 67 | 54 | 37 | 158 | 53 | 41 | 66 | 160 | 49 | 44 | 62 | 155 | 64 | 50 | 55 | 169 |
| 7 | 68 | 76 | 54 | 198 | 46 | 50 | 82 | 178 | 62 | 46 | 71 | 179 | 53 | 44 | 55 | 152 |
| 8 | 61 | 56 | 44 | 161 | 45 | 43 | 58 | 146 | 44 | 38 | 50 | 132 | 53 | 39 | 46 | 138 |
| 9 | 88 | 91 | 72 | 251 | 68 | 63 | 102 | 233 | 65 | 59 | 77 | 201 | 83 | 66 | 68 | 217 |
| 10 | 106 | 100 | 72 | 278 | 71 | 71 | 103 | 245 | 80 | 69 | 93 | 242 | 87 | 72 | 81 | 240 |
| 11 | 112 | 93 | 70 | 275 | 65 | 70 | 101 | 236 | 90 | 61 | 88 | 239 | 77 | 68 | 76 | 221 |
| 12 | 80 | 63 | 49 | 192 | 45 | 47 | 68 | 160 | 58 | 44 | 55 | 157 | 58 | 48 | 53 | 159 |

SERIES 2

| Day | a | b | c | Total | a | b | c | Total | a | b | c | Total | a | b | c | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 45 | 22 | 39 | 106 | 29 | 42 | 49 | 120 | 33 | 31 | 47 | 111 | 31 | 39 | 39 | 109 |
| 2 | 134 | 52 | 96 | 282 | 67 | 81 | 122 | 270 | 67 | 86 | 118 | 271 | 79 | 100 | 100 | 279 |
| 3 | 104 | 51 | 88 | 243 | 64 | 71 | 95 | 230 | 65 | 74 | 96 | 235 | 71 | 76 | 91 | 238 |
| 4 | 78 | 38 | 64 | 180 | 43 | 54 | 72 | 169 | 51 | 52 | 73 | 176 | 50 | 52 | 65 | 167 |
| 5 | 67 | 25 | 54 | 146 | 32 | 44 | 62 | 138 | 43 | 49 | 61 | 153 | 45 | 41 | 58 | 144 |
| 6 | 102 | 55 | 88 | 245 | 59 | 80 | 88 | 227 | 73 | 83 | 101 | 257 | 63 | 60 | 77 | 200 |
| 7 | 91 | 34 | 66 | 191 | 45 | 53 | 58 | 156 | 44 | 46 | 61 | 151 | 53 | 48 | 53 | 154 |
| 8 | 71 | 31 | 48 | 150 | 32 | 41 | 60 | 133 | 37 | 40 | 54 | 131 | 37 | 35 | 46 | 118 |
| 9 | 101 | 44 | 83 | 228 | 47 | 60 | 66 | 173 | 58 | 57 | 63 | 178 | 54 | 57 | 58 | 169 |
| 10 | 82 | 45 | 87 | 214 | 49 | 66 | 71 | 186 | 58 | 60 | 67 | 185 | 47 | 52 | 56 | 155 |
| 11 | 103 | 52 | 98 | 253 | 57 | 73 | 85 | 215 | 65 | 72 | 80 | 217 | 60 | 60 | 74 | 194 |
| 12 | 159 | 67 | 134 | 360 | 93 | 100 | 113 | 306 | 100 | 98 | 106 | 304 | 94 | 99 | 101 | 294 |

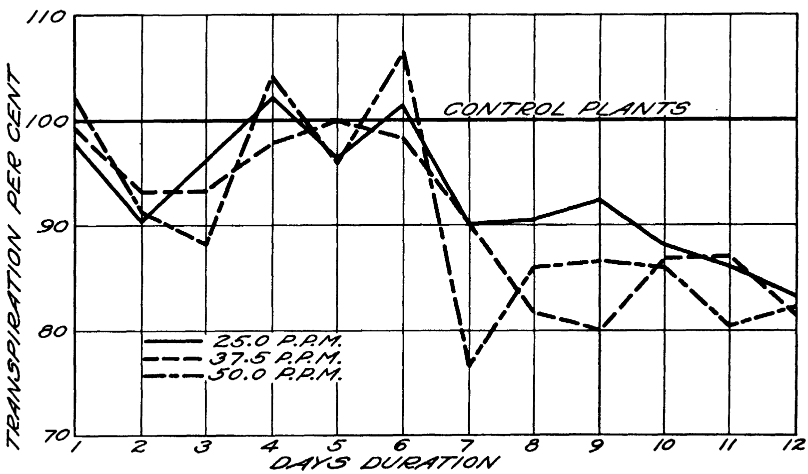


FIG. 1.—Daily loss of water by Everbearing tomato plants growing in soil, with and without the addition of 25, 37.5, and 50 parts per million of arsenic trioxide on the sixth day of the experiment. One hundred indicates total loss of water by the control plants. (Data from Table 4, series 1)

TABLE 5.—*Daily loss of water by Everbearing tomato plants growing in soil, with and without the addition of arsenic trioxide, the chemical added after the plants were weighed on the sixth day*

SERIES 1

| Day | Loss of water in grams by control | | | | Loss of water in grams after addition of— Arsenic 10 parts per million | | | | Arsenic 15 parts per million | | | | Arsenic 20 parts per million | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | a | b | c | Total | a | b | c | Total | a | b | c | Total | a | b | c | Total |
| 1 | 67 | 58 | 60 | 185 | 99 | 81 | 72 | 252 | 70 | 62 | 87 | 219 | 93 | 74 | 62 | 229 |
| 2 | 90 | 73 | 79 | 242 | 115 | 108 | 96 | 319 | 89 | 82 | 109 | 280 | 120 | 98 | 80 | 298 |
| 3 | 60 | 47 | 42 | 149 | 70 | 59 | 56 | 185 | 63 | 52 | 66 | 181 | 77 | 55 | 54 | 186 |
| 4 | 110 | 97 | 95 | 302 | 137 | 133 | 110 | 380 | 124 | 108 | 136 | 368 | 156 | 124 | 100 | 380 |
| 5 | 78 | 66 | 74 | 218 | 91 | 91 | 87 | 269 | 87 | 63 | 108 | 258 | 106 | 92 | 84 | 282 |
| 6 | 95 | 89 | 81 | 265 | 117 | 110 | 93 | 320 | 117 | 102 | 126 | 345 | 140 | 104 | 92 | 336 |
| 7 | 75 | 62 | 65 | 202 | 86 | 92 | 80 | 258 | 85 | 71 | 94 | 250 | 106 | 90 | 81 | 277 |
| 8 | 118 | 110 | 95 | 323 | 130 | 128 | 115 | 373 | 132 | 101 | 142 | 375 | 141 | 128 | 105 | 374 |
| 9 | 118 | 110 | 104 | 332 | 121 | 113 | 126 | 360 | 130 | 97 | 137 | 364 | 135 | 121 | 118 | 374 |
| 10 | 145 | 134 | 119 | 398 | 145 | 125 | 147 | 417 | 151 | 102 | 157 | 410 | 137 | 134 | 137 | 408 |
| 11 | 123 | 118 | 116 | 357 | 124 | 104 | 112 | 340 | 131 | 90 | 135 | 356 | 122 | 108 | 113 | 343 |
| 12 | 75 | 64 | 58 | 197 | 76 | 73 | 65 | 214 | 76 | 55 | 86 | 217 | 77 | 72 | 68 | 217 |

SERIES 2

| Day | a | b | c | Total | a | b | c | Total | a | b | c | Total | a | b | c | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 244 | 166 | 188 | 598 | 170 | 176 | 133 | 479 | 203 | 219 | 204 | 626 | 161 | 193 | 214 | 568 |
| 2 | 199 | 142 | 153 | 494 | 149 | 145 | 125 | 419 | 156 | 183 | 167 | 506 | 146 | 159 | 193 | 498 |
| 3 | 252 | 194 | 194 | 640 | 190 | 187 | 165 | 542 | 176 | 220 | 228 | 624 | 196 | 205 | 242 | 643 |
| 4 | 190 | 154 | 154 | 498 | 145 | 172 | 149 | 466 | 148 | 195 | 176 | 519 | 159 | 165 | 179 | 503 |
| 5 | 268 | 217 | 221 | 706 | 213 | 229 | 203 | 645 | 205 | 237 | 244 | 686 | 241 | 231 | 266 | 738 |
| 6 | 173 | 135 | 140 | 448 | 133 | 164 | 146 | 443 | 134 | 164 | 151 | 449 | 148 | 142 | 159 | 449 |
| 7 | 150 | 114 | 117 | 381 | 105 | 134 | 133 | 372 | 111 | 130 | 126 | 367 | 125 | 121 | 137 | 383 |
| 8 | 116 | 87 | 94 | 297 | 84 | 107 | 92 | 283 | 88 | 101 | 100 | 289 | 94 | 92 | 98 | 284 |
| 9 | 180 | 131 | 132 | 443 | 133 | 151 | 136 | 420 | 135 | 141 | 143 | 419 | 146 | 139 | 152 | 437 |
| 10 | 153 | 122 | 128 | 403 | 126 | 161 | 138 | 425 | 125 | 138 | 147 | 410 | 130 | 135 | 145 | 410 |
| 11 | 148 | 113 | 120 | 381 | 129 | 142 | 121 | 392 | 119 | 126 | 131 | 376 | 131 | 124 | 140 | 395 |
| 12 | 97 | 80 | 88 | 265 | 91 | 111 | 90 | 292 | 81 | 100 | 102 | 283 | 92 | 91 | 97 | 280 |

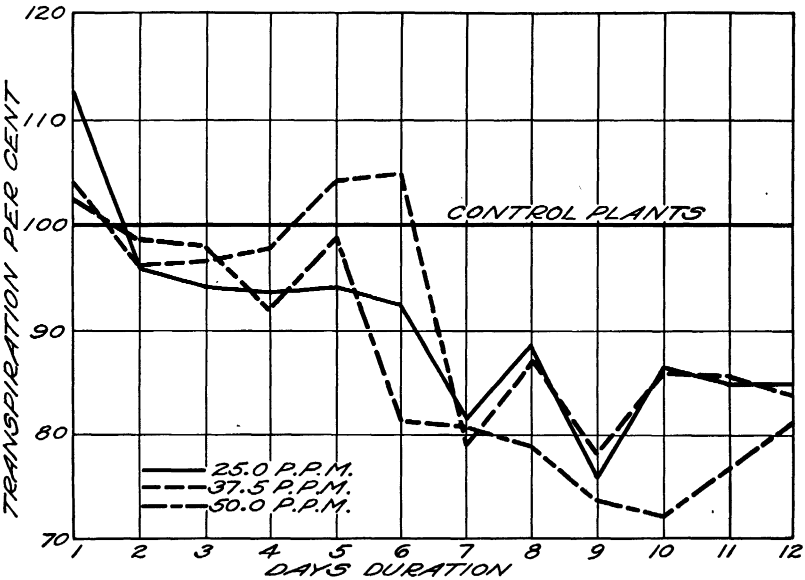


FIG. 2.—Daily loss of water by Everbearing tomato plants growing in soil, with and without the addition of 25, 37.5, and 50 parts per million of arsenic trioxide on the sixth day of the experiment. One hundred indicates total loss of water by the control plants. (Data from Table 4, series 2.)

TABLE 6.—*Daily loss of water by Earliana tomato plants growing in 6-inch pots of garden soil, with and without the addition of sodium arsenite (0.01 gm.) and potassium arsenite (0.10 gm.) the chemicals added after the plants were weighed on the sixth day*

| Day | Loss of water in grams by— | | |
|---|---|---|---|
| | Plant 1, untreated | Plant 2, treated with sodium arsenite | Plant 3, treated with potassium arsenite |
| 1 | 115. 0 | 142. 5 | 129. 0 |
| 2 | 113. 0 | 135. 5 | 111. 0 |
| 3 | 83. 5 | 102. 0 | 83. 5 |
| 4 | 66. 0 | 85. 0 | 72. 5 |
| 5 | 121. 0 | 156. 5 | 150. 0 |
| 6 | 201. 0 | 271. 5 | 246. 0 |
| 7 | 194. 5 | 217. 0 | 153. 5 |
| 8 | 231. 5 | 296. 5 | 157. 0 |
| 9 | 141. 0 | 150. 5 | 82. 5 |
| 10 | 245. 0 | 287. 0 | 152. 0 |
| 11 | 283. 5 | 277. 5 | 138. 5 |
| 12 | 165. 0 | 188. 5 | 107. 0 |
| 13 | 201. 5 | 232. 0 | 122. 0 |
| 14 | 182. 5 | 222. 0 | 111. 5 |
| 15 | 265. 0 | 270. 5 | 127. 0 |
| 16 | 250. 5 | 242. 5 | 125. 0 |
| 17 | 210. 5 | 216. 5 | 131. 0 |
| 18 | 167. 5 | 178. 5 | 96. 0 |
| 19 | 104. 5 | 113. 0 | 59. 0 |
| 20 | 242. 5 | 245. 5 | 139. 0 |

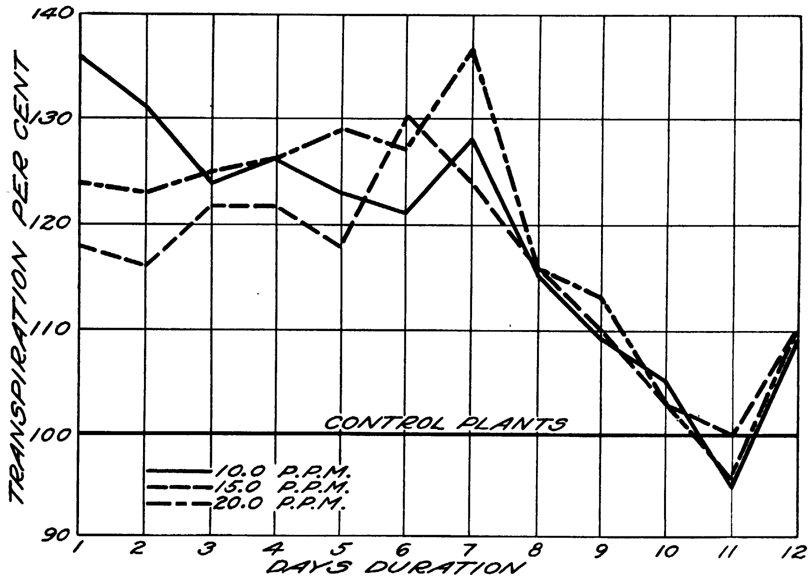


FIG. 3.—Daily loss of water by Everbearing tomato plants growing in soil, with and without the addition of 10, 15, and 20 parts per million of arsenic trioxide on the sixth day of the experiment. One hundred indicates total loss of water by the control plants. (Data from Table 5, series 1.)

TABLE 7.—*Daily loss of water by Earliana tomato plants growing in 6-inch pots of garden soil. Sodium arsenite (0.05 gm.) added to each pot after the plants were weighed on the sixth day*

TREATED PLANTS

| Date | Loss of water in grams by plant No. | | | | | | Total loss of water | Hours between weighing | Average loss (grams per hour) |
|---|---|---|---|---|---|---|---|---|---|
| | 3 | 5 | 7 | 8 | 10 | 11 | | | |
| 1913 | | | | | | | | | |
| Feb. 27 | 86.0 | 82.5 | 89.5 | 85.5 | 48.5 | 95.0 | 487.0 | 23.0 | 21.2 |
| Feb. 28 | 78.5 | 85.5 | 98.0 | 99.0 | 50.5 | 103.5 | 515.0 | 25.0 | 20.6 |
| Mar. 1 | 86.0 | 110.5 | 123.5 | 145.0 | 75.0 | 127.5 | 667.5 | 25.0 | 26.7 |
| Mar. 2 | 80.0 | 62.0 | 61.5 | 76.5 | 39.0 | 68.0 | 387.0 | 22.0 | 17.6 |
| Mar. 3 | 127.0 | 132.0 | 141.0 | 155.5 | 89.5 | 149.0 | 794.0 | 24.0 | 33.1 |
| Mar. 4 | 95.5 | 101.5 | 95.0 | 128.0 | 64.0 | 112.0 | 596.0 | 24.0 | 24.8 |
| Mar. 5 | 126.0 | 129.5 | 131.0 | 155.5 | 94.5 | 163.0 | 799.5 | 25.0 | 32.0 |
| Mar. 6 | 60.5 | 63.0 | 71.0 | 86.0 | 45.0 | 82.0 | 407.5 | 23.0 | 17.7 |
| Mar. 7 | 67.0 | 94.5 | 102.0 | 113.5 | 82.0 | 142.0 | 601.0 | 24.0 | 25.0 |
| Mar. 8 | 90.0 | 113.0 | 118.0 | 108.0 | 82.0 | 117.0 | 628.0 | 24.0 | 26.2 |
| Mar. 9 | 111.0 | 133.0 | 138.0 | 145.0 | 98.0 | 225.0 | 850.0 | 25.0 | 34.0 |
| Mar. 10 | 129.0 | 166.0 | 145.0 | 165.0 | 110.0 | 200.0 | 915.0 | 27.5 | 33.3 |
| Mar. 11 | 37.0 | 47.0 | 37.0 | 43.0 | 28.0 | 47.0 | 239.0 | 19.3 | 12.4 |
| Mar. 12 | 77.0 | 108.0 | 98.0 | 96.0 | 77.0 | 112.0 | 568.0 | 24.0 | 23.7 |
| Mar. 13 | 84.0 | 118.0 | 93.0 | 92.0 | 90.0 | 113.0 | 590.0 | 24.0 | 24.6 |
| Mar. 14 | 70.0 | 100.0 | 83.0 | 73.0 | 92.0 | 95.0 | 513.0 | 24.0 | 21.4 |
| Mar. 15 | 113.0 | 169.0 | 130.0 | 114.0 | 159.0 | 178.0 | 863.0 | 25.0 | 36.5 |
| Mar. 16 | 112.0 | 150.0 | 120.0 | 107.0 | 119.0 | 152.0 | 760.0 | 24.5 | 31.0 |
| Mar. 17 | 85.0 | 115.0 | 95.0 | 85.0 | 113.0 | 114.0 | 607.0 | 23.0 | 26.4 |
| Mar. 18 | 66.0 | 111.0 | 82.0 | 82.0 | 131.0 | 140.0 | 612.0 | 24.5 | 25.0 |
| Mar. 19 | 146.0 | 211.0 | 147.0 | 141.0 | 124.0 | 124.0 | 893.0 | 29.5 | 30.3 |
| Mar. 20 | 83.0 | 48.0 | 80.0 | 77.0 | 102.0 | 87.0 | 477.0 | 24.5 | 19.5 |
| Mar. 21 | 60.0 | 103.0 | 69.0 | 52.0 | 90.0 | 85.0 | 459.0 | 22.5 | 20.4 |
| Mar. 22 | 104.0 | 157.0 | 109.0 | 82.0 | 124.0 | 107.0 | 683.0 | 24.0 | 28.5 |
| Mar. 23 | 54.0 | 93.0 | 68.0 | 43.0 | 57.0 | 65.0 | 380.0 | 21.0 | 18.1 |
| Mar. 24 | 116.0 | 221.0 | 160.0 | 109.0 | 149.0 | 180.0 | 935.0 | 29.0 | 32.2 |
| Mar. 25 | 84.0 | 122.0 | 87.0 | 57.0 | 83.0 | 90.0 | 523.0 | 24.0 | 21.8 |
| Mar. 26 | 78.0 | 117.0 | 86.0 | 64.0 | 98.0 | 88.0 | 531.0 | 23.0 | 23.1 |
| | 2,505.5 | 3,263.0 | 2,857.5 | 2,779.5 | 2,514.0 | 3,361.0 | 17,280.5 | ---------- | ---------- |

CONTROLS

| Date | Loss of water in grams by plant No. | | | | | | Total loss of water | Hours between weighing | Average loss (grams per hour) |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 4 | 6 | 9 | 12 | | | |
| 1913 | | | | | | | | | |
| Feb. 27 | 79.5 | 94.0 | 96.0 | 102.5 | 85.0 | 69.0 | 526.0 | 23.0 | 22.9 |
| Feb. 28 | 101.5 | 102.0 | 84.0 | 92.0 | 89.0 | 65.0 | 533.5 | 25.0 | 21.3 |
| Mar. 1 | 105.0 | 100.5 | 118.5 | 112.5 | 109.0 | 81.5 | 627.0 | 25.0 | 25.1 |
| Mar. 2 | 96.0 | 96.5 | 60.5 | 58.0 | 56.0 | 41.0 | 408.0 | 22.0 | 18.5 |
| Mar. 3 | 152.0 | 154.0 | 138.5 | 130.0 | 123.0 | 68.0 | 765.5 | 24.0 | 31.9 |
| Mar. 4 | 124.0 | 119.0 | 92.0 | 90.5 | 81.5 | 57.5 | 564.5 | 24.0 | 23.5 |
| Mar. 5 | 145.5 | 151.0 | 140.0 | 132.0 | 134.0 | 108.0 | 810.5 | 25.0 | 32.4 |
| Mar. 6 | 74.0 | 80.0 | 55.5 | 71.0 | 65.0 | 56.0 | 401.5 | 23.0 | 17.5 |
| Mar. 7 | 156.0 | 167.0 | 151.0 | 149.0 | 161.0 | 134.0 | 918.0 | 24.0 | 38.3 |
| Mar. 8 | 176.0 | 204.0 | 157.0 | 181.0 | 160.0 | 117.0 | 995.0 | 24.0 | 41.5 |
| Mar. 9 | 178.0 | 195.0 | 163.0 | 167.0 | 210.0 | 143.0 | 1,056.0 | 25.0 | 42.2 |
| Mar. 10 | 197.0 | 225.0 | 200.0 | 170.0 | 207.0 | 137.0 | 1,136.0 | 27.5 | 41.3 |
| Mar. 11 | 77.5 | 81.0 | 73.0 | 47.0 | 56.0 | 43.0 | 377.5 | 19.3 | 19.6 |
| Mar. 12 | 129.5 | 130.5 | 139.5 | 102.0 | 144.0 | 102.0 | 747.5 | 24.0 | 31.1 |
| Mar. 13 | 131.0 | 142.0 | 150.0 | 109.0 | 172.0 | 122.0 | 826.0 | 24.0 | 34.4 |
| Mar. 14 | 112.0 | 114.0 | 128.0 | 97.0 | 140.0 | 103.0 | 694.0 | 24.0 | 28.9 |
| Mar. 15 | 176.0 | 219.0 | 208.0 | 169.0 | 239.0 | 183.0 | 1,194.0 | 25.0 | 47.8 |
| Mar. 16 | 179.0 | 201.0 | 173.0 | 139.0 | 162.0 | 122.0 | 976.0 | 24.5 | 39.8 |
| Mar. 17 | 131.0 | 143.0 | 159.0 | 105.0 | 152.0 | 117.0 | 807.0 | 23.0 | 35.1 |
| Mar. 18 | 100.0 | 111.0 | 107.0 | 78.0 | 199.0 | 148.0 | 743.0 | 24.5 | 30.3 |
| Mar. 19 | 206.0 | 229.0 | 217.0 | 170.0 | 184.0 | 139.0 | 1,145.0 | 29.5 | 38.8 |
| Mar. 20 | 109.0 | 137.0 | 126.0 | 117.0 | 164.0 | 146.0 | 799.0 | 24.5 | 32.6 |
| Mar. 21 | 127.0 | 146.0 | 158.0 | 116.0 | 176.0 | 154.0 | 877.0 | 22.5 | 39.0 |
| Mar. 22 | 213.0 | 234.0 | 219.0 | 175.0 | 219.0 | 180.0 | 1,240.0 | 24.0 | 51.7 |
| Mar. 23 | 106.0 | 124.0 | 82.0 | 90.0 | 99.0 | 90.0 | 591.0 | 21.0 | 28.1 |
| Mar. 24 | 271.0 | 316.0 | 246.0 | 230.0 | 264.0 | 211.0 | 1,538.0 | 29.0 | 53.0 |
| Mar. 25 | 148.0 | 162.0 | 143.0 | 117.0 | 169.0 | 117.0 | 856.0 | 24.0 | 35.7 |
| Mar. 26 | 142.0 | 151.0 | 168.0 | 123.0 | 175.0 | 169.0 | 928.0 | 23.0 | 40.3 |
| Mar. 27 | 273.0 | 309.0 | 249.0 | 214.0 | 246.0 | 209.0 | 1,500.0 | 25.0 | 60.0 |
| Mar. 28 | 153.0 | 147.0 | 145.0 | 98.0 | 201.0 | 109.0 | 853.0 | 23.0 | 37.1 |
| Mar. 29 | 116.0 | 85.0 | 99.0 | 57.0 | 73.0 | 43.0 | 473.0 | 24.0 | 19.7 |
| Mar. 30 | 144.0 | 89.0 | 105.0 | 64.0 | 58.0 | 39.0 | 499.0 | 24.0 | 20.8 |
| Mar. 31 | 119.0 | 77.0 | 88.0 | 53.0 | 44.0 | 30.0 | 411.0 | 25.0 | 16.4 |
| Apr. 1 | 81.0 | 63.0 | 72.0 | 42.0 | 41.0 | 28.0 | 327.0 | 23.0 | 14.2 |
| Apr. 2 | 173.0 | 118.0 | 138.0 | 84.0 | 74.0 | 65.0 | 652.0 | 26.0 | 25.1 |
| | 5,001.5 | 5,216.5 | 4,848.5 | 4,051.5 | 4,931.5 | 3,746.0 | 27,795.5 | ---------- | ---------- |

From a study of these tables and figures it is apparent that arsenic added as arsenic trioxide decreased the transpiration of tomato plants to a greater or less extent when the plants were grown in soil. The tables emphasize the fact that considerable variation in the quantity of water lost by the same plant occurs from day to day. These variations are due mainly to meteorological conditions.

In Figure 1 it is shown that a decided effect was produced on transpiration by the addition of arsenic trioxide in quantities of 25, 37.5, and 50 parts per million. While some variation occurred from day to day, at the end of the experiment the loss of water by the treated plants was from 80 to 85 per cent of that lost by the controls as compared to 97 per cent or more at the time the chemical was added. Figure 2, a graphic representation of a duplicate of this experiment, shows similar results.

Figures 3 and 4, where smaller quantities of arsenic trioxide were used, indicate a considerable effect on transpiration from the addition

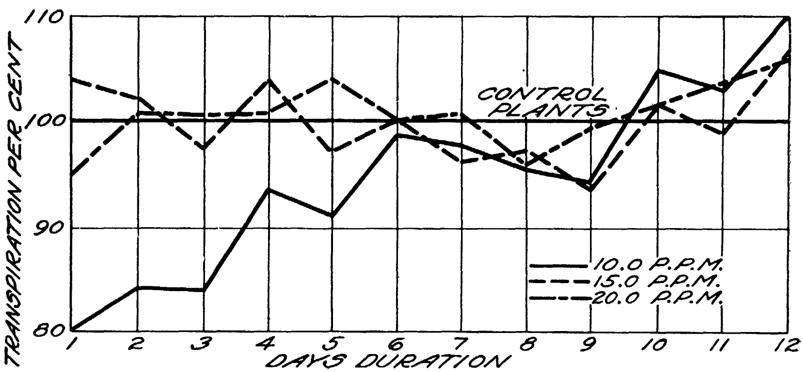


FIG. 4.—Daily loss of water by Everbearing tomato plants growing in soil, with and without the addition of 10, 15, and 20 parts per million of arsenic trioxide on the sixth day of the experiment. One hundred indicates total loss of water by the control plants. (Data from Table 5, series 2.)

of the chemical. In Figure 3 the treated plants on the sixth day averaged 126 per cent total transpiration in comparison with that of the controls, and on the eleventh day they averaged only 97 per cent, indicating that the chemical influenced transpiration.

Figure 4 shows a small decrease for three days, and then a marked tendency toward recovery. In all cases where only small quantities of arsenic trioxide were added, the plants showed a tendency to recover after a certain length of time, which in these experiments varied usually from 2 to 5 days.

The fact that the loss of water by the control plants shown in the different graphs was higher or lower than by the treated plants is not significant since there was considerable variation and all data were comparable.

## TRANSPIRATION STUDIES WITH TOMATO PLANTS POTTED IN SAND

Quartz sand No. 3.5, a commercial product obtained from Ottawa, Ill., was screened through standard 20 and 40 mesh sieves, and only that part was used which passed through the 20-mesh sieve and was retained by the 40-mesh. The sand was thoroughly digested with weak hydrochloric acid for 48 hours and then washed with distilled water until no acid reaction was noted with methyl orange as in indicator. The water-retaining capacity of the sand was about 11 per cent.

The tomato plants used in the experiments were grown in soil, and at the time of transplanting were about 5 inches high. As much of the soil as possible was removed from their roots and they were transplanted in glazed earthenware jars containing 2,500 gm. of air-dried sand. The nutrient solution (p. 3) was added to bring the moisture content to 15 per cent of the air-dried weight of the sand.

The plants were allowed to grow for about a month before the experiment was begun. During this interval an additional 125 gm. of the nutrient solution was added besides the distilled water necessary to replace the loss through transpiration.

During the experiment the jars were so sealed as to allow no loss of water except through the aerial parts of the plant. Daily an amount of distilled water equal to that lost by the plant was added. The loss was determined by weighing on scales sensitive to 0.5 gm. Arsenic trioxide in solution was added to the plants by a method similar to that described under soil cultures. The results of this experiment are shown in Table 8 and Figure 5.

TABLE 8.—*Daily loss of water by Everbearing tomato plants growing in sand, with and without the addition of arsenic trioxide, the chemical added after the plants were weighed on the sixth day*

| Day | Loss of water by control | | | | Loss of water after addition of arsenic, 10 parts per million | | | | Loss of water after addition of arsenic, 20 parts per million | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | a | b | c | Total | a | b | c | Total | a | b | c | Total |
| | *Gm.* | *Gm.* | *Gm.* | *Gm.* | *Gm.* | *Gm.* | *Gm.* | *Gm.* | *Gm.* | *Gm.* | *Gm.* | *Gm.* |
| 1 | 60 | 35 | 60 | 155 | 22 | 32 | 39 | 93 | 46 | 47 | 45 | 138 |
| 2 | 90 | 55 | 98 | 243 | 30 | 47 | 60 | 137 | 75 | 74 | 75 | 224 |
| 3 | 65 | 40 | 70 | 175 | 22 | 32 | 44 | 98 | 55 | 51 | 52 | 158 |
| 4 | 101 | 70 | 112 | 283 | 38 | 66 | 76 | 180 | 89 | 83 | 91 | 263 |
| 5 | 65 | 49 | 77 | 191 | 27 | 43 | 54 | 124 | 60 | 57 | 65 | 182 |
| 6 | 102 | 80 | 110 | 292 | 48 | 70 | 80 | 198 | 97 | 88 | 109 | 294 |
| 7 | 63 | 52 | 69 | 184 | 25 | 30 | 30 | 85 | 25 | 33 | 33 | 91 |
| 8 | 71 | 67 | 90 | 228 | 19 | 24 | 26 | 69 | 21 | 24 | 20 | 65 |
| 9 | 82 | 81 | 107 | 270 | 13 | 27 | 33 | 73 | 18 | 22 | 22 | 62 |
| 10 | 106 | 105 | 142 | 353 | 23 | 39 | 46 | 108 | 20 | 29 | 27 | 76 |
| 11 | 54 | 45 | 59 | 158 | 16 | 20 | 26 | 62 | 14 | 19 | 19 | 52 |
| 12 | 43 | 35 | 57 | 135 | 16 | 23 | 28 | 67 | 16 | 25 | 23 | 64 |

From these it is apparent that arsenic decreases the transpiration of tomato plants when they are grown in sand. Table 8 shows that considerable variation in the loss of water occurs from day to day, a fact which is mainly due to meteorological conditions. The injury is apparent in a shorter period of time in sand than in soil, when equal quantities of arsenic trioxide are added and transpiration is used as a criterion. Compare Figure 3 with Figure 5. After the fourth day there is a marked tendency toward recovery.

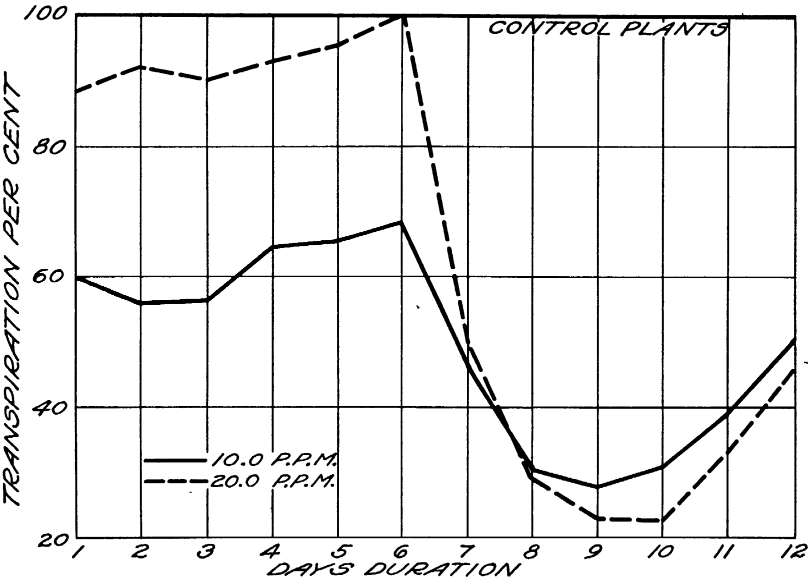


FIG. 5.—Daily loss of water by Everbearing tomato plants growing in sand, with and without the addition of 10 and 20 parts per million of arsenic trioxide on the sixth day of the experiment. One hundred indicates total loss of water by the control plants. (Data from Table 8.)

## EFFECT ON GROWTH OF POTTED PLANTS CAUSED BY ADDITION OF SOLUBLE ARSENICAL COMPOUNDS TO THE SOIL

The plants in this group of experiments were grown in 6-inch pots full of garden soil. Table 9 gives the variety of plant and its condition at the time of treatment, and Table 10 shows the effect produced by the chemicals on the various plants. Potassium or sodium arsenite proved to be highly toxic to practically all the plants. The other compounds were only slightly toxic to the cereals. In the same family or group there was noted a wide variation in tolerance of the chemical, as, for example, arsenic acid and potassium arsenate in the quantities added proved fatal to radish and caused only slight injury to turnip. Sodium arsenate killed the oat plants, but apparently caused no injury to barley or wheat.

TABLE 9.—*Condition of plants prior to treatment with soluble arsenicals as shown in Table 10*

| Plant | Variety | Height in inches | Condition |
|---|---|---|---|
| Barley | New Zealand | 10–14 | Stems slender, normal color. |
| Bean A | Prolific German Wax | 15–25 | Vigorous growth, normal color. |
| Bean B | White Navy | 15–25 | Vigorous growth, normal color. |
| Cabbage | Large Premium | 6–12 | Fair condition, light green in color. |
| Clover | Mammoth Red | 5 | Leaves normal in size and color. |
| Corn | White Flint | 21–27 | Stalks slender, normal color. |
| Cucumber | Improved Long Green | 8–12 | Vigorous growth, normal color. |
| Lettuce | Hanson | 6 | Leaves 4–5 inches wide, normal color. |
| Oats | Swedish Select White Wonder | 10–18 | Stems weak but erect, normal color. |
| Pea | Canadian Field | 7–22 | Somewhat spindling growth, normal color. |
| Radish | White Strasburg | 8–14 | 6–8 leaves, stems slender, normal color. |
| Squash | Hubbard | 8–12 | Vigorous growth, normal color. |
| Timothy | | 12–20 | Spindling growth of stems, light green color. |
| Tomato A | Early Michigan | 8–10 | Vigorous growth, normal color. |
| Tomato B | Perfection | 8–10 | Vigorous growth, normal color. |
| Turnip | | 6–12 | Roots small to 2 inches in diameter, normal color. |
| Wheat | Glyndon 650 | 14–20 | Stems somewhat weak, normal color. |

TABLE 10.—*Effect on potted plants caused by the addition to the soil of 0.5 gm. of soluble arsenicals*

| Plant used | Effect on plant caused by addition to soil of— | | | | | |
|---|---|---|---|---|---|---|
| | Arsenic acid | Ammonium arsenate | Potassium arsenate | Sodium arsenate | Potassium arsenite | Sodium arsenite |
| Barley | No injury | No injury | No injury | No injury | Very bad | Dead. |
| Bean A | Dead | Very bad | Dead | Dead | Dead | Do. |
| Bean B | | Dead | do | do | do | Do. |
| Cabbage | | | | | | Do. |
| Clover | | | | Dead | | Do. |
| Corn | No injury | No injury | Moderate | No injury | Very bad to dead | Do. |
| Cucumber | Dead | Dead | | | | Do. |
| Lettuce | do | | No injury | No injury | Dead | Do. |
| Oats | No injury | No injury | do | Dead | Bad | Do. |
| Pea | | | | | | Do. |
| Radish | Dead | No injury | Dead | No injury | Dead | Do. |
| Squash | | | | do | | Do. |
| Timothy | | | | | | Do. |
| Tomato A | Dead | Dead | Moderate | No injury | Dead | Do. |
| Tomato B | Bad | do | No injury | do | do | Do. |
| Turnip | No injury | No injury | Slight | do | No injury | Bad. |
| Wheat | do | do | No injury | do | Dead | Dead. |

## EFFECT ON GROWTH OF POTTED PLANTS CAUSED BY ADDITION OF INSOLUBLE ARSENICAL COMPOUNDS TO THE SOIL

The plants in these experiments were grown in 6-inch pots full of garden soil. Table 11 shows the effect on growth produced by adding 2.5 gm. of the arsenical, which was sprinkled as evenly as possible over the surface of each pot. The control plants made a satisfactory growth, and remained in a good healthy condition throughout the experiment.

TABLE 11.—*Effect on the growth of various plants in 6-inch pots caused by the addition to the soil of 2.5 gm. of arsenic compounds*

| Arsenic compound used | Effect of arsenical on— | | | | | |
|---|---|---|---|---|---|---|
| | Barley | Carrot | Oats | Sugar beet | Tomato A | Wheat |
| Arsenic (metal) | Very injurious. | Dead | | | | |
| Arsenic trioxide | No injury | Slightly stunted | | | Slightly stunted. | |
| Calcium arsenate | do | Moderately stunted | | | do | |
| Copper arsenate | | Badly stunted | No injury | | No injury | |
| Ferrous arsenate | | do | | | do | |
| Lead arsenate | | Slightly stunted | No injury | | do | |
| Mercury(ic) arsenate | | do | | | | No injury. |
| Zinc arsenate | | Badly stunted | | Dead | Dead | Do. |
| Calcium arsenite | | | | do | | Dead. |
| Copper arsenite | | | No injury | Slightly stunted. | Dead | |
| Iron and ammonia arsenite. | | Moderate stunted | | No injury | | Dead. |
| Zinc arsenite | | do | | do | | |
| Arsenic sulphide, red | | | | do | | |
| Lead arsenite | | | No injury | | Injurious | |

The so-called "insoluble" arsenical compounds are arranged below in the order of their toxicity as indicated by the injury which they caused to bean and tomato. Those listed first caused severe injury; those preceded by an asterisk caused none.

BEAN

| | | |
|---|---|---|
| Amonium arsenate | Lead arsenite | Lead arsenate |
| Zinc arsenate | Copper arsenite | Mercuric arsenate |
| Arsenic metal | Zinc arsenite | Ferric arsenite and ammonium citrate |
| Calcium arsenite | Arsenic trioxide | *Arsenic disulphide, red |
| Mercurous arsenite | Calcium arsenate | *Copper arsenate |
| Arsenic sulphide, yellow | Ferrous arsenate | |

TOMATO

| | | |
|---|---|---|
| Arsenic metal | Arsenic sulphide, yellow | *Ferrous arsenate |
| Calcium arsenite | Zinc arsenite | *Lead arsenite |
| Ammonium arsenate | Arsenic trioxide | *Ferric arsenite and ammonium citrate |
| Mercurous arsenite | Mercuric arsenate | *Arsenic disulphide, red |
| Copper arsenite | *Calcium arsenate | *Lead arsenate |
| Zinc arsenate | *Copper arsenate | |

These results indicate that plants show an individuality in their reaction to chemical compounds, which may vary greatly with different species.

## EFFECT ON GROWTH OF CROPS CAUSED BY INCORPORATION OF ARSENICAL COMPOUNDS IN THE SOIL

The ground selected for the work reported in this section was a uniform strip of medium clay loam slightly sloping to the west. The ground was prepared by the ordinary method used for making a good seed bed. It was then staked out into plots 3 feet square with 2-foot alleys running north and south and east and west. Figure 6 shows the arrangement of the plots, the cropping system, and the arsenical compounds used. This system remained uniform throughout the experiment unless otherwise noted. Each year the plots except the alfalfa, clover, and timothy were spaded, thoroughly worked, and planted. The original planting was as follows: Wheat, timothy, alfalfa, and clover in 5 rows running north and south, and 6 inches apart. Sugar beets and field peas in 3 rows running north and south, and 12 inches apart. The first row in all cases was 6 inches from the margin of the plot. Potatoes, cabbage, and tomatoes were set 4 plants to a plot, equidistant and 10 inches from the margin.[3] Cucumbers were planted about 2 inches apart in a circular hill 16 inches in diameter.

The plots were watered by a revolving sprinkler to prevent any washing of the surface soil. The chemicals used and the quantities added at each treatment were as follows (each plot received an equivalent amount of arsenic, approximately 11 gm., as determined by the results of analysis made by members of the chemistry department of the Montana station):

| Chemical | Grams per treatment | Chemical | Grams per treatment |
|---|---|---|---|
| Arsenic trioxide | 14. 58 | Lead arsenate ertho | 63. 10 |
| Arsenic trisulphide | 18. 03 | Lead arsenite | 30. 50 |
| Calcium arsenite | 20. 82 | Sodium arsenite | 18. 33 |
| Copper aceto-arsenite | 24. 55 | Sodium arsenate | 43. 07 |
| Lead arsenate pyro | 50. 00 | Zinc arsenite | 20. 10 |

[3] The cabbage and tomato plants were transplanted from 4-inch pots when they were about 5 inches tall

TABLE 12.—*Growth of plants in plots of soil treated with different arsenicals*

CABBAGE

| Year | Plot treated with— | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Arsenic trioxide | Arsenic trisulphide | Calcium arsenite | Copper aceto-arsenite | Lead arsenate acid | Lead arsenate ortho | Lead arsenite | Sodium arsenate | Sodium arsenite | Zinc arsenite | Control 1 | Control 2 |
| 1911 [a] | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good. |
| 1912 | Fair | Moderate | Fair | Poor | Moderate | Poor | Fair | Fair | Moderate | Poor | do | Do. |
| 1913 [b] | do | Poor | None | do | do | Good | Poor | None | Poor | None | do | Do. |
| 1914 [c] | | | | | | | | | | | | |
| 1915 [b] | Moderate | Fair | Poor | do | Good | Moderate | None | Poor | None | Fair | do | Moderate. |
| 1916 | Good | do | do | do | do | Good | Good | None | Moderate | do | do | Good. |
| 1917 [a] | Fair | Poor | do | do | Moderate | Moderate | Fair | Fair | Fair | Poor | do | Do. |
| 1918 | Moderate | Fair | do | Fair | Good | Good | Moderate | Moderate | Moderate | do | do | Do. |
| 1919 | None | None | Moderate | Moderate | Fair | Moderate | Good | Fair | Good | Fair | do | Moderate. |
| 1920 | Poor | Moderate | Fair | Fair | Moderate | do | Fair | Moderate | do | Poor | do | Good. |
| 1921 | do | Fair | do | do | Good | do | Good | Fair | Fair | do | Moderate | Do. |
| 1922 | Good | Good | Good | Good | do | Good | do | Good | Good | Good | Good | Do. |

CUCUMBER

| Year | Arsenic trioxide | Arsenic trisulphide | Calcium arsenite | Copper aceto-arsenite | Lead arsenate acid | Lead arsenate ortho | Lead arsenite | Sodium arsenate | Sodium arsenite | Zinc arsenite | Control 1 | Control 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1911 [a] | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good. |
| 1912 | Moderate | Fair | None | Poor | Moderate | Moderate | Poor | Poor | Fair | None | do | Do. |
| 1913 [b] | None | None | do | None | None | None | None | None | None | do | do | Do. |
| 1914 | do | do | do | do | do | do | do | do | do | do | Moderate | Do. |
| 1915 [a] | do | do | do | do | Poor | do | do | Poor | do | do | Good | Do. |
| 1916 | Poor | Poor | do | Poor | do | do | do | do | do | Poor | do | Do. |
| 1917 | None | do | do | None | do | Poor | do | do | Poor | do | do | Do. |
| 1918 | Poor | Fair | Poor | Fair | do | None | Poor | do | do | Fair | do | Do. |
| 1919 | do | Poor | do | Poor | do | do | do | Fair | Fair | Poor | do | Do. |
| 1920 | do | do | do | do | Fair | do | do | do | do | do | do | Do. |
| 1921 | do | Fair | do | do | Poor | Poor | do | do | do | Fair | do | Do. |
| 1922 [d] | | | | | | | | | | | | |

FIELD PEA

| Year | Arsenic trioxide | Arsenic trisulphide | Calcium arsenite | Copper aceto-arsenite | Lead arsenate acid | Lead arsenate ortho | Lead arsenite | Sodium arsenate | Sodium arsenite | Zinc arsenite | Control 1 | Control 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1911 [a] | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good. |
| 1912 | do | Moderate | Moderate | Moderate | do | do | Moderate | Moderate | Moderate | Poor | do | Do. |
| 1913 [b] | do | Poor | None | Fair | do | do | Poor | Poor | Fair | None | do | Do. |
| 1914 | do | do | do | Poor | Moderate | Fair | do | do | Poor | do | do | Do. |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1915 [b] | Moderate | Fair | Fair | Fair | do | Moderate | Fair | do | Fair | Fair | do | Do. |
| 1916 | Poor | None | None | None | Poor | Poor | None | None | None | None | do | Do. |
| 1917 | do | Poor | do | Poor | Fair | Fair | Poor | do | Poor | Poor | do | Do. |
| 1918 | do | Moderate | Fair | Moderate | Moderate | do | Fair | Fair | Fair | Fair | do | Do. |
| 1919 | Good | Fair | Poor | do | do | do | do | Moderate | Moderate | Good | do | Do. |
| 1920 | Moderate | do | do | Fair | Good | Moderate | Poor | Good | Fair | Poor | do | Do. |
| 1921 | Fair | Moderate | Moderate | Poor | None | Poor | do | Fair | None | Moderate | do | Do. |
| 1922 | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | do | Do. |
| **POTATO** | | | | | | | | | | | | |
| 1911 [a] | Good | Moderate | Poor | Fair | Good | Moderate | Fair | Moderate | Poor | Fair | Good | Good. |
| 1912 | do | Good | Good | Good | do | Good | Good | Good | Good | Good | do | Do. |
| 1913 [b] | do | do | do | do | do | do | do | Moderate | do | do | do | Do. |
| 1914 | do | Fair | Fair | Poor | Moderate | Moderate | Fair | Poor | Fair | Poor | do | Fair. |
| 1915 [b] | Moderate | do | Poor | Fair | Good | Good | do | do | do | do | do | Moderate. |
| 1916 | Good | Moderate | Fair | do | do | do | Moderate | do | do | do | do | Do. |
| 1917 [a] | do | Fair | do | do | Moderate | Moderate | Fair | Fair | Moderate | do | do | Good. |
| 1918 | do | do | Good | Good | Good | Good | Moderate | do | Fair | do | Moderate | Do. |
| 1919 | Moderate | Poor | Fair | Fair | do | Moderate | Good | Good | do | do | do | Do. |
| 1920 | Fair | Moderate | Moderate | Moderate | do | Good | Moderate | do | Moderate | Fair | Fair | Do. |
| 1921 | Poor | Fair | Good | do | do | do | Good | do | do | do | do | Moderate. |
| 1922 | Good | Good | do | Good | do | do | do | do | Good | Good | Good | Good. |
| **TOMATO** | | | | | | | | | | | | |
| 1911 [a] | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good. |
| 1912 | do | do | do | do | do | do | do | do | do | do | do | Do. |
| 1913 [b] | Moderate | Moderate | Fair | Fair | Moderate | Moderate | Moderate | Moderate | do | Poor | do | Do. |
| 1914 | do | Fair | do | do | do | do | Fair | Fair | Moderate | do | do | Do. |
| 1915 [b] | do | do | do | do | do | do | do | do | Fair | do | do | Do. |
| 1916 | Good | Moderate | Poor | Moderate | Good | Good | do | Poor | Poor | None | do | Do. |
| 1917 [a] | Moderate | Poor | None | None | Moderate | Moderate | Poor | do | do | do | do | Do. |
| 1918 | Fair | do | Poor | Poor | Good | Good | Moderate | do | do | do | do | Do. |
| 1919 | Good | Moderate | do | Moderate | do | do | Fair | do | Moderate | do | do | Do. |
| 1920 | Moderate | Fair | do | do | do | do | Moderate | Moderate | Good | Fair | Moderate | Fair. |
| 1921 [e] | | | | | | | | | | | | |
| 1922 [e] | | | | | | | | | | | | |

[a] Chemical treatment given that year.
[b] Treatment before planting and after harvest.
[c] Growth was generally very poor in 1914 on account of injury caused by worms.
[d] Plots not planted.
[e] No difference observed.

TABLE 12—*Growth of plants in plots of soil treated with different arsenicals*—Continued

SUGAR BEET

| Year | Plot treated with— | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Arsenic trioxide | Arsenic trisulphide | Calcium arsenite | Copper aceto-arsenite | Lead arsenate acid | Lead arsenate ortho | Lead arsenite | Sodium arsenate | Sodium arsenite | Zinc arsenite | Control 1 | Control 2 |
| 1911 [a] | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good. |
| 1912 | do | Poor | Moderate | Moderate | Moderate | Moderate | Fair | Moderate | do | Fair | do | Do. |
| 1913 [b] | Poor | Moderate | Fair | do | Fair | Fair | do | Poor | Fair | do | do | Do. |
| 1914 | Good | Good | Very poor | Poor | Good | Moderate | Moderate | do | do | Very poor | do | Do. |
| 1915 [b] | do | Moderate | Fair | Moderate | do | Good | do | do | Moderate | None | do | Do. |
| 1916 | Fair | Poor | None | Poor | Fair | Moderate | Poor | None | None | do | do | Do. |
| 1917 [a] | Poor | Very poor | do | None | Moderate | do | do | Poor | Poor | do | do | Do. |
| 1918 | Moderate | Fair | Good | Moderate | do | Fair | Moderate | do | Fair | Good | do | Do. |
| 1919 | Fair | Good | Fair | Fair | Good | Good | do | do | Poor | do | Moderate | Moderate. |
| 1920 | Moderate | Moderate | Poor | do | Fair | Fair | Fair | Moderate | Good | Moderate | Good | Fair. |
| 1921 | Fair | Good | Moderate | do | do | do | Moderate | Fair | Fair | do | do | Good. |
| 1922 | Moderate | Fair | do | do | Good | Moderate | Good | Moderate | Moderate | do | do | Do. |

WHEAT

| Year | Arsenic trioxide | Arsenic trisulphide | Calcium arsenite | Copper aceto-arsenite | Lead arsenate acid | Lead arsenate ortho | Lead arsenite | Sodium arsenate | Sodium arsenite | Zinc arsenite | Control 1 | Control 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1911 [a] | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good. |
| 1912 | do | do | Moderate | Moderate | do | do | do | Fair | do | Fair | do | Do. |
| 1913 [b] | do | do | Poor | Fair | do | do | Poor | None | Poor | None | do | Do. |
| 1914 | do | Poor | do | Poor | Moderate | do | do | do | None | do | do | Do. |
| 1915 [b] | Moderate | Fair | Fair | Fair | do | Moderate | Fair | Poor | Poor | Fair | do | Do. |
| 1916 | do | Poor | Poor | Poor | Fair | Fair | Poor | None | None | Poor | do | Do. |
| 1917 [a] | do | do | None | None | do | do | do | Poor | Poor | None | do | Do. |
| 1918 | None | None | Poor | Poor | Moderate | Moderate | None | do | do | do | do | Do. |
| 1919 | do | Poor | Fair | Fair | Good | do | Fair | Fair | Fair | Poor | do | Do. |
| 1920 | Poor | None | Poor | Poor | do | do | Poor | Moderate | None | None | do | Do. |
| 1921 | do | do | do | Fair | do | Good | Fair | do | Fair | do | do | Do. |
| 1922 | do | do | Fair | do | do | do | Poor | Good | Poor | do | Moderate | Do. |

[a] Chemical treatment given that year.
[b] Treatment before planting and after harvest.

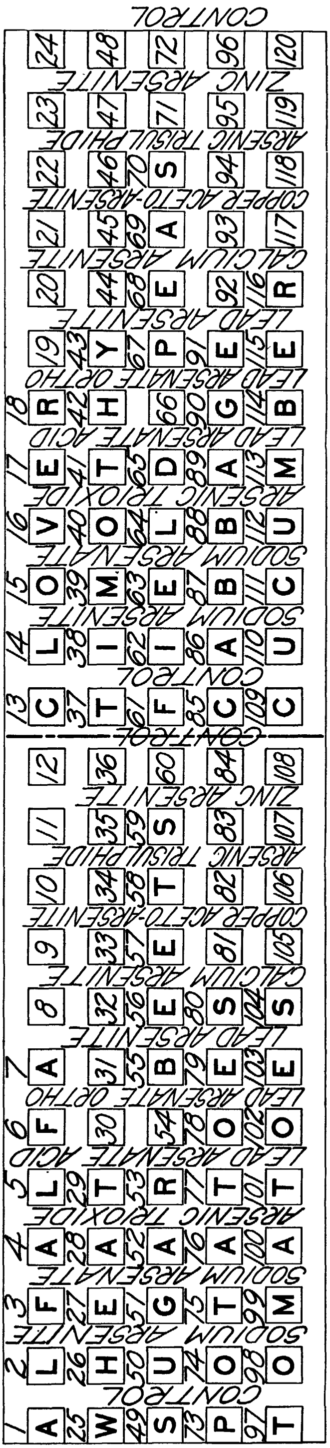


FIG. 6.—Diagram showing arrangement of plots, cropping system, and arsenical used in experiments made to determine the effect on the growth of crops caused by the incorporation of arsenical compounds in the soil

During the first year only the chemical was added by sprinkling it evenly over the surface of the soil while the crops were growing. All the other treatments were given in the fall after the crops were harvested, or in the spring before planting and incorporated in the soil.

The alfalfa, clover, and timothy plots proved very unsatisfactory owing to winter-killing and the intrusion of other grasses and weeds. These plots were abandoned and no detailed notes were taken on them.

Tables 12 and 13 indicate the time of treatment and the yearly rating of the season's growth of the different crops, namely, cabbage, cucumber, field peas, potatoes, tomato, sugar beet, and wheat, and the toxicity of the various arsenicals in relation to the crop.

TABLE 13.—*Toxicity of arsenicals to different crops* [a]

[Ranking from 1 (poor growth) to 10 (approximately normal growth)]

| Arsenical | Toxicity of arsenical to— | | | | | |
|---|---|---|---|---|---|---|
| | Cabbage | Peas | Potato | Tomato | Sugar beet | Wheat |
| Arsenic trioxide | 5 | 9 | 9 | 8 | 6 | 8 |
| Arsenic trisulphide | 6 | 5 | 3 | 4 | 9 | 7 |
| Calcium arsenite | 3 | 2 | 4 | 2 | 2 | 3 |
| Copper aceto-arsenite | 2 | 4 | 5 | 5 | 8 | 4 |
| Lead arsenate acid | 10 | 10 | 10 | 9 | 10 | 10 |
| Lead arsenate ortho | 9 | 8 | 8 | 10 | 7 | 9 |
| Lead arsenite | 8 | 1 | 7 | 6 | 3 | 6 |
| Sodium arsenate | 4 | 7 | 6 | 3 | 1 | 2 |
| Sodium arsenite | 7 | 3 | 2 | 7 | 4 | 5 |
| Zinc arsenite | 1 | 6 | 1 | 1 | 5 | 1 |

[a] All arsenicals injured the growth of cucumbers to such an extent that ranking was impossible.

From a critical examination of the data contained in Table 12 it appears that some chemicals become inactive very much sooner than others and that the amount of injury caused by the chemicals varies from year to year with different crops. In all the experiments the final addition of arsenic was made in 1917, and the plots were continually cropped until 1922 in order to determine the rapidity with which the soil would again produce normal growth. At no time did lead arsenate cause much injury, whereas zinc arsenite caused severe injury throughout the entire time. The degree of injury attributable to the other chemicals ranged between these extremes, as is shown by the data in Table 12.

## SUMMARY

The results of transpiration studies with oats in water cultures show conclusively that arsenic added as arsenic trioxide decreases transpiration even when added at the rate of one part per million. The characteristics of treated plants are narrower leaf blades and a lighter color. There is apparent individuality in the reaction of plants to this arsenical.

Decreased transpiration resulted when arsenic trioxide was added at the rate of 10 parts per million or more to soil in which tomato plants were growing, and this decrease was more apparent in direct proportion to the amount of arsenic added until serious injury or death resulted.

Similar results were obtained when sodium arsenite or potassium arsenite was substituted for arsenic trioxide.

When sand was used instead of soil, the other environmental conditions remaining the same, the injury was apparent in a shorter time. Considerable variation occurred from day to day, mainly due to meteorological conditions.

The addition of small quantities of soluble arsenical compounds to potted plants caused serious injury to most of the plants under test. As a rule the cereals were hardier than the other crops. Turnip was also fairly resistant. The arsenites were decidedly more toxic than the arsenates.

Some of the so-called "insoluble" arsenical compounds proved very toxic to plants when 2.5 gm. of the chemical was sprinkled evenly over the surface of the pot.

The toxicity of arsenical chemicals to plants varied. Some species showed a high, and to others a low, degree of tolerance to the same arsenical.

The incorporation of arsenical compounds in the soil is a dangerous practice, and may cause considerable injury as the concentration of arsenic increases. Arsenical compounds differ in their reaction in the soil, some becoming inert in a much shorter period than others. Plants also differ in their ability to withstand arsenic, as is illustrated by the fact that some crops remain approximately normal when arsenic in some form is present, while other crops in the same environment are killed. Beans and cucumbers are very susceptible to arsenic, but the cereals and grasses are much more resistant.

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